The Electromagnetic Spectrum

The *electromagnetic spectrum* is the distribution of electromagnetic radiation according to energy (or equivalently, by virtue of the relations in the previous section, according to frequency or wavelength).

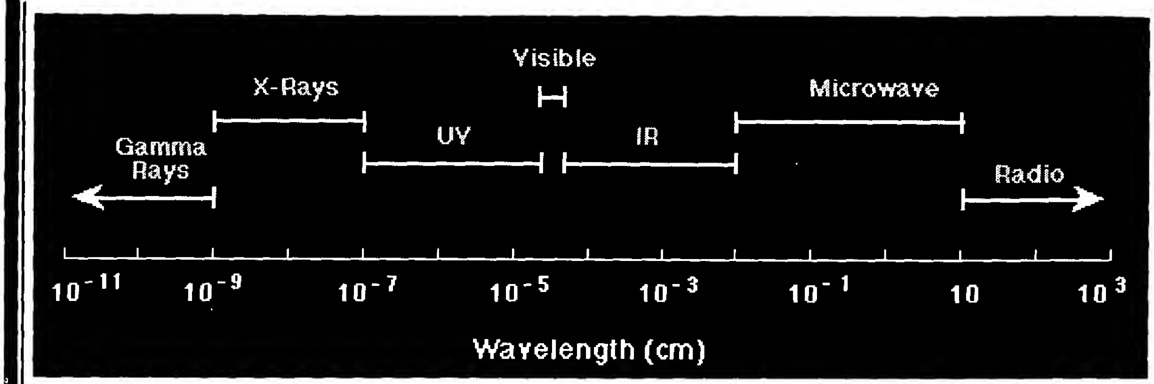
Regions of the Electromagnetic Spectrum

The following table gives approximate wavelengths, frequencies, and energies for selected regions of the electromagnetic spectrum.

Spectrum of Electromagnetic Radiation

Region	Wavelength (Angstroms)	Wavelength (centimeters)	Frequency (Hz)	Energy (eV)
Radio	$> 10^9$	> 10	$< 3 \times 10^9$	$< 10^{-5}$
Microwave	$10^9 - 10^6$	$10 - 0.01$	$3 \times 10^9 - 3 \times 10^{12}$	$10^{-5} - 0.01$
Infrared	$10^6 - 7000$	$0.01 - 7 \times 10^{-5}$	$3 \times 10^{12} - 4.3 \times 10^{14}$	$0.01 - 2$
Visible	$7000 - 4000$	$7 \times 10^{-5} - 4 \times 10^{-5}$	$4.3 \times 10^{14} - 7.5 \times 10^{14}$	$2 - 3$
Ultraviolet	$4000 - 10$	$4 \times 10^{-5} - 10^{-7}$	$7.5 \times 10^{14} - 3 \times 10^{17}$	$3 - 10^3$
X-Rays	$10 - 0.1$	$10^{-7} - 10^{-9}$	$3 \times 10^{17} - 3 \times 10^{19}$	$10^3 - 10^5$
Gamma Rays	< 0.1	$< 10^{-9}$	$> 3 \times 10^{19}$	$> 10^5$

The notation "eV" stands for electron-volts, a common unit of energy measure in atomic physics. A graphical representation of the electromagnetic spectrum is shown in the figure below.

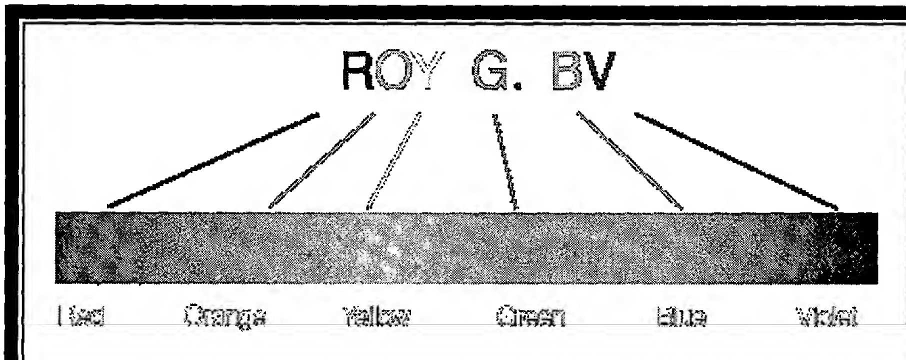


The electromagnetic spectrum

Thus we see that visible light and gamma rays and microwaves are really the same things. They are all electromagnetic radiation; they just differ in their wavelengths.

The Spectrum of Visible Light

The visible part of the spectrum may be further subdivided according to color, with red at the long wavelength end and violet at the short wavelength end, as illustrated (schematically) in the following figure.



The visible spectrum

How Roy G. Bv Lost a Vowel

The sequence of colors red, orange, yellow, green, blue, and violet may be remembered by memorizing the name of that fine fellow "ROY G. BV". This was originally "ROY G. BIV", because it used to be common to call the region between blue and violet "indigo". In modern usage, indigo is not usually distinguished as a separate color in the visible spectrum; thus Roy no longer has any vowels in his last name.

Pesticides
BeerShots
Cocktail Collection
Screen Savers
Win Wallpaper
Mac Wallpaper
Movie Gallery

spectrum.

Tungsten light sources are commonly labeled ***incandescent*** because they radiate light when heated by electrical energy. Fluorescent light is generated as a result of electrical current traveling through a charged gas.

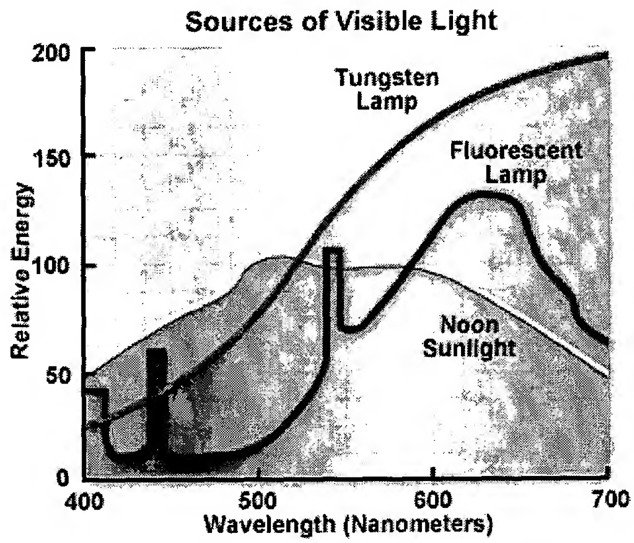


Figure 2

Figure 2 presents spectral distribution curves demonstrating the relative amounts of energy vs. wavelength in three different types of "white" light. The red spectrum represents the relative energy of tungsten light over the visible spectrum. As is apparent, the energy of tungsten light increases as wavelength increases, which dramatically affects the average **color temperature** of the resultant light, especially when it is compared to that of natural sunlight and fluorescent light. The yellow spectrum represents what we see with a natural sunlight spectrum sampled at noon. Under normal circumstances sunlight would have the greatest amount of energy, but we have normalized the spectrum in order to compare it to the other two. The blue spectrum is seen with fluorescent light and contains some notable differences from the tungsten and natural sunlight spectra. Several energy peaks are present in the fluorescent light spectrum that are a result of the superposed line spectrum of mercury vapor in a fluorescent lamp.

Interactive Java Tutorial

Color Temperature

Discover how a black body radiator can be heated to emit a variety of color spectra.

GO JAVA

There are a variety of non-incandescent visible light sources that are used for microscopy, indoor, and outdoor lighting. Most of these are based on electronic discharge in a gas such as mercury or the noble gases neon, argon, and xenon (Figure 3). The generation of visible light in these devices relies on the collision of atom and ions in the gas with the current that is discharged from the electrodes at the ends of the bulbs. This is illustrated in Figure 3 with a common fluorescent lamp.

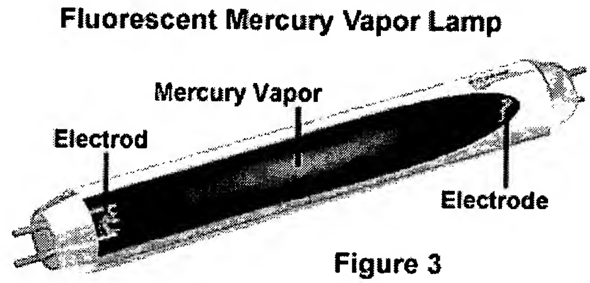


Figure 3

The glass tube of the lamp is coated with phosphor on the inside and the tube is filled with mercury vapor at very low pressure. An electric current is applied to the electrodes at the ends of the tube, producing a stream of electrons. When the electrons collide with mercury atoms, they excite electrons in the atoms to higher energy states. This energy is released in the form of ultraviolet radiation when the mercury atoms return to the ground state. The ultraviolet radiation energizes the internal phosphor coating causing it to emit the bright white light that we see from fluorescent lights.

A unique feature of these light sources is that the wavelengths they generate are often concentrated in narrow bands called ***line spectra***. Unfortunately, these sources do not produce a continuous spectrum similar to incandescent sources. A good example of an almost exclusively single wavelength source of non-incandescent visible light are sodium-vapor lamps used in street lighting. These lamps emit a very intense yellow light with over 95 percent being composed of 589 nanometer light with virtually no other colors.

It is possible to design gas-discharge lamps that will emit a moderately continuous spectrum in addition to the line spectra inherent in most of these lamps. The most common method is to coat the inside surface of the tube with phosphor particles. These particles will absorb radiation emitted by the glowing gas and convert it into light ranging from red to blue.

Under normal circumstances most people are not able to discern the mixture of a line and continuous spectrum. However, some objects reflect unusual colors in this environment, particularly under fluorescent light. This is why clothing purchased in a store illuminated by fluorescent light appears a slightly different color under natural sunlight or continuous tungsten illumination.

Another source of visible light that is becoming increasingly more important in our everyday lives is laser illumination. The acronym **LASER** stands for **L**ight **A**mplification by the **S**timulated **E**mission of **R**adiation.

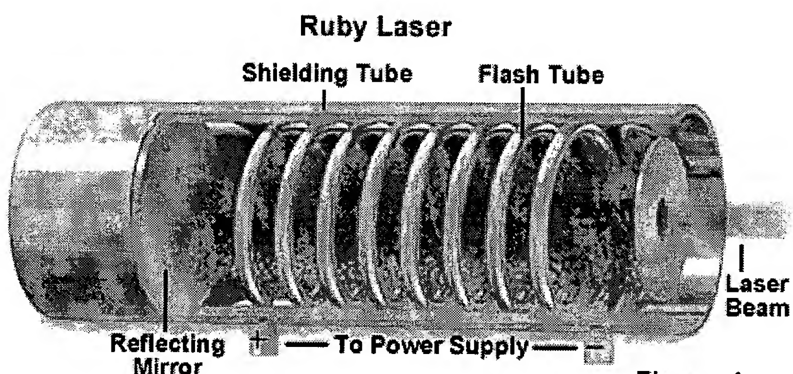


Figure 4

The laser illustrated in Figure 4 is a ruby laser that emits red light when atoms in the crystal are excited with a flash tube. Several unique features of lasers is that they emit a continuous beam of light made up of a single wavelength that exits in a single phase, commonly termed ***coherent light***. The wavelength of light emitted by a laser depends upon the material from which the laser crystal or gas is composed. Lasers do not actually generate light, they only amplify it. In the example above, the light produced in the gaseous mixture is bounced back and forth between the two mirrored surfaces

at the ends of the laser tube steadily increasing in energy. When a critical threshold is reached, light is emitted from the slightly transparent mirror on one end of the laser tube. We have simulated a ruby laser in our **interactive Java Laser Tutorial**.

Interactive Java Tutorial

Laser Light Sources

Explore how a ruby laser is excited by a xenon flash tube to produce coherent red light.

GO! JAVA

Lasers are used in a number of applications ranging compact disk readers to measuring and surgical devices. Their application to optical microscopy is also growing and will be discussed later in this primer.

From our discussion, it is apparent that although there are a wide variety of illumination sources, we generally rely on only a few throughout our everyday lives. During daylight hours the sun serves as our main source of illumination outdoors, while we generally rely on fluorescent and tungsten lighting while indoors and during the evening hours. As discussed above, these three primary lighting sources all have different properties and spectral characteristics, but their maximum intensities all fall within the visible light range. The human brain adjusts automatically to the different light sources and we interpret the colors of most objects around us as hardly changing when they are viewed under differing conditions of illumination.

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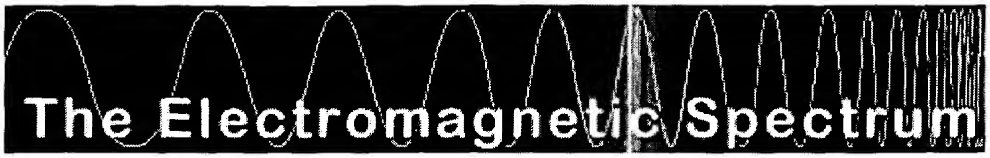
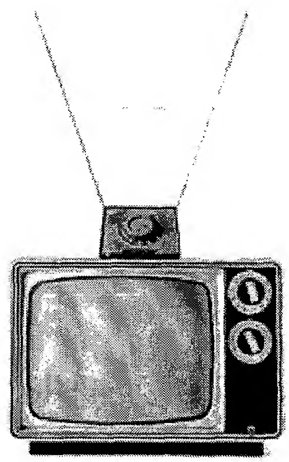
BACK TO LIGHT AND COLOR

Questions or comments? Send us an email.

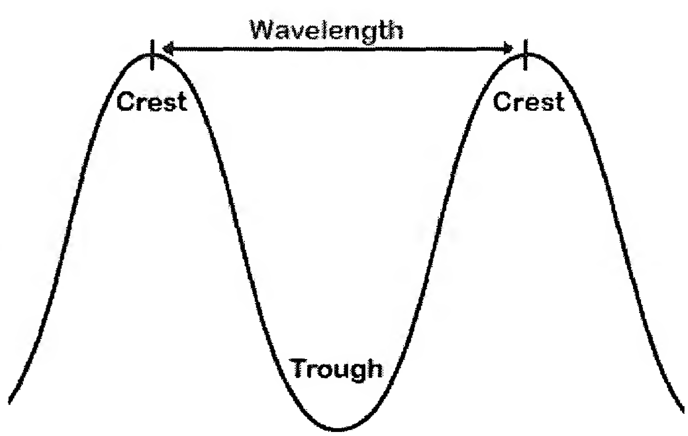


Electromagnetic Waves have different wavelengths.

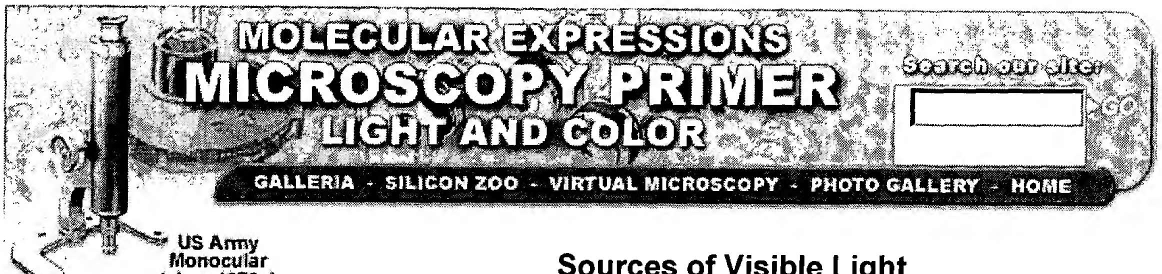
When you listen to the radio, watch TV, or cook dinner in a microwave oven, you are using electromagnetic waves.



Radio waves, television waves, and microwaves are all types of electromagnetic waves. They only differ from each other in wavelength. Wavelength is the distance between one wave crest to the next.



Waves in the electromagnetic spectrum vary in size from very long radio waves the size of buildings, to very short gamma-rays smaller than the size of the nucleus of an atom.



US Army Monocular (circa 1870s)

Microscopy Primer
Light and Color
Microscope Anatomy
Special Techniques
Photomicrography
Microscopy Museum
Virtual Microscopy
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Sources of Visible Light

Visible light comprises only a tiny portion of the entire electromagnetic spectrum of radiation. The wavelengths that we are able to see lie between between 400 and 700 nanometers in length. As we have discussed in the section on **frequency** and **wavelength**, all electromagnetic radiation is the result of the decay of photons and gamma rays from atoms. The visible light that we are able to see (Figure 1) is usually a mixture of wavelengths whose composition is a function of the light source.

Visible Light Spectrum

Figure 1

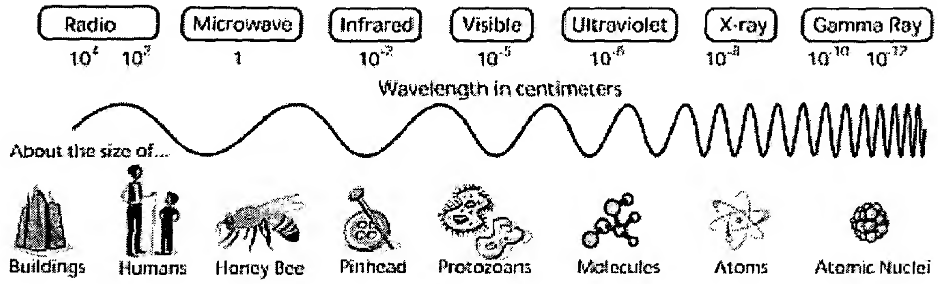
In our day-to-day lives, we are bombarded by an enormous spectrum of electromagnetic radiation, only a portion of which we are able to actually "see" as visible light. When venturing outside, a vast majority of the light we see is emitted from the sun, which also emits many other frequencies of radiation that do not fall in the visible range. Inside, we are exposed to visible light that comes from "artificial" sources primarily originating from fluorescent and/or tungsten devices.

Visible Light Wavelength and Perceived Color

Wavelength Range (nanometers)	Perceived Color
340-400	Near Ultraviolet (UV; Invisible)
400-430	Violet
430-500	Blue
500-560	Green
560-620	Yellow to Orange
620-700	Orange to Red
Over 700	Near Infrared (IR; Invisible)

Table 1

Table 1 contains a listing of the apparent color distribution perceived by humans for each set of wavelengths in the visible spectrum. Quantification of color is a useful relationship that makes it easy to differentiate between different hues and shades. It is possible for many different spectral distributions to produce identical color sensations. A yellow color sensation may be caused by a single wavelength of light, for instance 590 nanometers, or it may be the result of viewing two single wavelengths such as 590 and 600 nanometers. It is also possible to view the color yellow as a narrow distribution involving all wavelengths between 590 and 600 nanometers. The same argument holds for all colors in the visible



Did you know that electromagnetic waves can not only be described by their wavelength, but also by their energy and frequency? All three of these things are related to each other mathematically. This means that it is correct to talk about the energy of an X-ray or the wavelength of a microwave or the frequency of a radio wave.

The electromagnetic spectrum includes, from longest wavelength to shortest: radio waves, microwaves, infrared, optical, ultraviolet, X-rays, and gamma-rays.

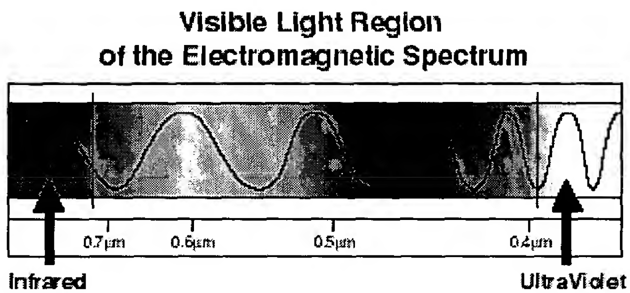
To tour the electromagnetic spectrum, follow the links below!

RADIO WAVES | MICROWAVES | INFRARED | VISIBLE LIGHT | ULTRAVIOLET | X-RAYS | GAMMA RAYS

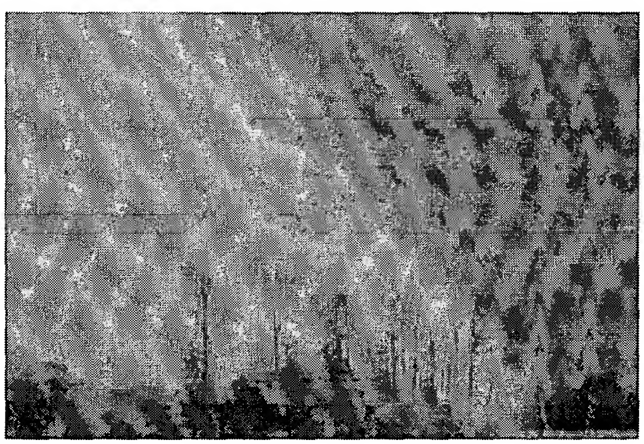
RETURN TO THE ELECTROMAGNETIC SPECTRUM

RADIO WAVES | MICROWAVES | INFRARED | VISIBLE LIGHT | ULTRAVIOLET | X-RAYS | GAMMA RAYS

Visible Light Waves



Visible light waves are the only electromagnetic waves we can see. We see these waves as the colors of the rainbow. Each color has a different wavelength. Red has the longest wavelength and violet has the shortest wavelength. When all the waves are seen together, they make white light.



When white light shines through a prism or through water vapor like this rainbow, the white light is broken apart into the colors of the visible light spectrum.

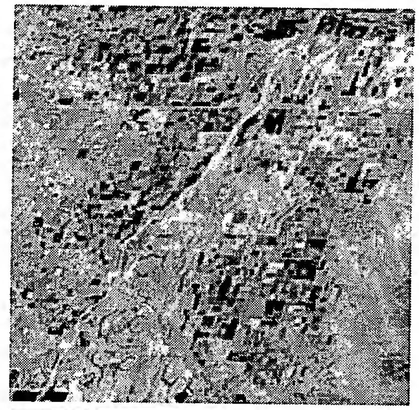
How do we "see" using Visible Light?

Cones in our eyes are receivers for these tiny visible light waves. The Sun is a natural source for visible light waves and our eyes see the reflection

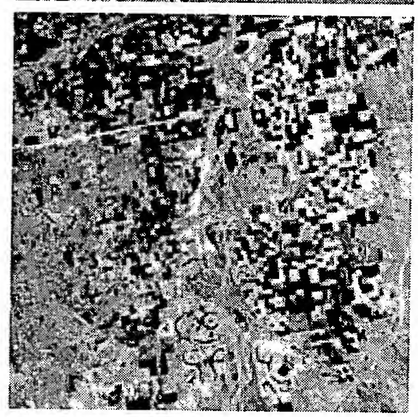
of this sunlight off the objects around us.

The color of an object that we see is the color of light reflected. All other colors are absorbed.

Light bulbs are another source of visible light waves.



This is an photograph taken from the space shuttle of Phoenix, Arizona.

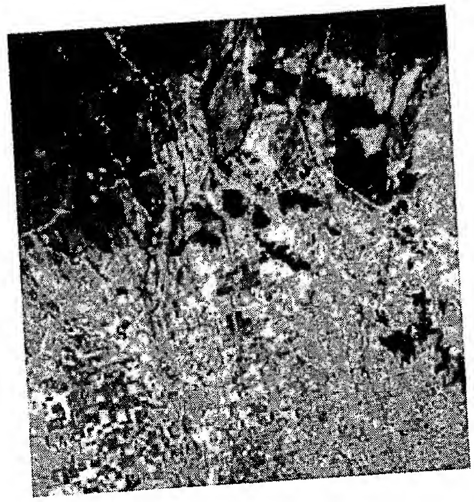


This is a true-color satellite image of Phoenix, Arizona. Can you see a difference between this image and the photo above it?

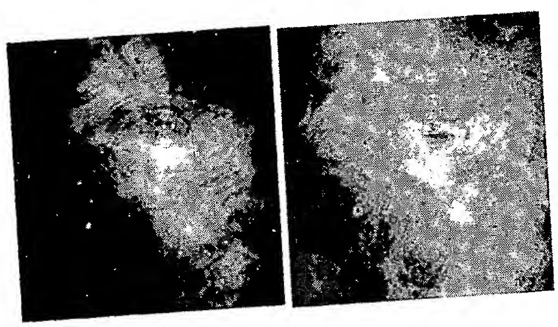
There are two types of color images that can be made from satellite data - true-color and false-color. To take true-color images, like this one, the satellite that took it used sensors to record data about the red, green, and blue visible light waves that were reflecting off the earth's surface. The data were combined later on a computer. The result is similar to what our eyes see.

Here is a false-color image of

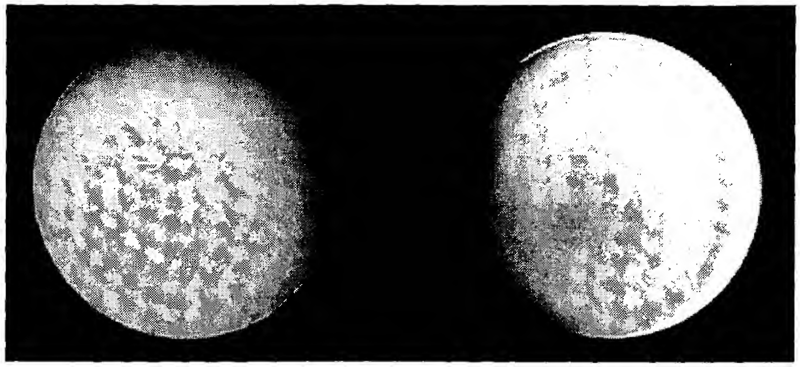
Phoenix. How does it compare to the true-color and space shuttle images on this page?



A false-color image is made when the satellite records data about brightness of the light waves reflecting off the Earth's surface. These brightnesses are represented by numerical values - and these values can then be color-coded. It is just like painting by number! The colors chosen to "paint" the image are arbitrary, but they can be chosen to either make the object look realistic, or to help emphasize a particular feature in the image. Astronomers can even view a region of interest by using software to change the contrast and brightness on the picture, just like the controls on a TV! Can you see a difference in the color palettes selected for the two images below? Both images are of the Crab Nebula, the remains of an exploded star!



Here's another example - the below pictures show the planet Uranus in true-color (on the left) and false-color (on the right).

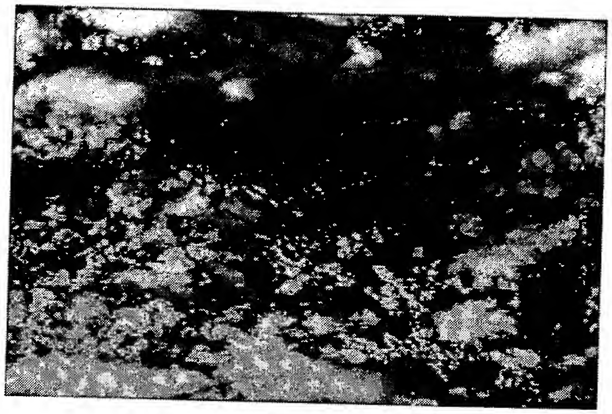


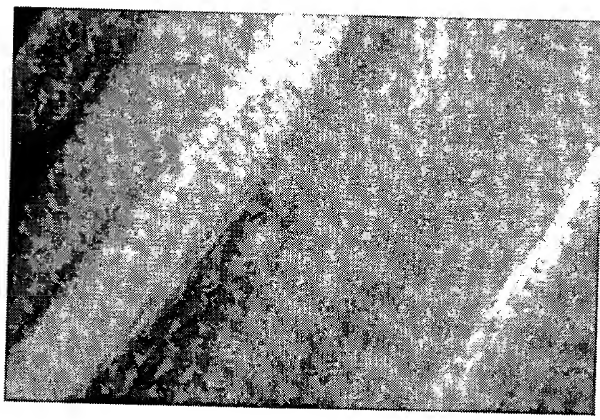
The true-color has been processed to show Uranus as human eyes would see it from the vantage point of the Voyager 2 spacecraft, and is a composite of images taken through blue, green and orange filters. The false color and extreme contrast enhancement in the image on the right, brings out subtle details in the polar region of Uranus. The very slight contrasts visible in true color are greatly exaggerated here, making it easier to studying Uranus' cloud structure. Here, Uranus reveals a dark polar hood surrounded by a series of progressively lighter concentric bands. One possible explanation is that a brownish haze or smog, concentrated over the pole, is arranged into bands by zonal motions of the upper atmosphere.

What does Visible Light show us?

It is true that we are blind to many wavelengths of light. This makes it important to use instruments that can detect different wavelengths of light to help us to study the Earth and the Universe. However, since visible light is the part of the electromagnetic spectrum that our eyes can see, our whole world is oriented around it. And many instruments that detect visible light can see father and more clearly than our eyes could alone. That is why we use satellites to look at the Earth, and telescopes to look at the Sky!

This is a visible light image of Phoenix, Arizona, taken from the GOES satellite. We often use visible light images to see clouds and to help predict the weather.





We not only look at the Earth from space but we can also look at other planets from space. This is a visible light image of the planet Jupiter. It is in false color - the colors were chosen to emphasize the cloud structure on this banded planet - Jupiter would not look like this to your eyes.

[NEXT LONGER WAVELENGTH][NEXT SHORTER WAVELENGTH]

RETURN TO THE ELECTROMAGNETIC SPECTRUM